Recycling of Polystyrene Cups via D-Limonene for use in Fabric

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Abstract

Our team has demonstrated a non-degradative method for cleanly and repeatedly recycling polystyrene (PS) drinking cups by dissolving them in d-limonene (D-L), an organic solvent derived from citrus rinds. This solvent is highly selective and only strongly dissolves PS among the common recycling polymers. It also removes common contaminants, as drink residues are water-based and non-soluble. The cleaned and separated PS can then be recovered from the D-L either via steam distillation, resulting in bulk PS, or via wet-spinning into a linear alkane, resulting in PS filament. This PS can then be reused, either for general PS uses such as drinking cups or styrofoam, or blended with other common polymers to produce a clothing-ready fabric.

Background and Motivation

Polystyrene: the disposal of polystyrene Solo cups creates environmental pollution due to PS' nondegradable nature

Oxidative Degradation: heating of PS in mechanical recycling techniques causes chain scission

Fashion Industry: among the most polluting industries in the world, second only to oil and gas.[1]

Currently, there are no broadly used industrial processes to recycle non-expanded polystyrene. Thus, our research methods have the potential to reduce worldwide plastics waste and set a new standard for sustainability in the fashion industry.

Process Design

1. Dissolution of mixed recyclables in D-L for cleaning and filtering out non-PS materials
2. Recovery of polystyrene via steam distillation or precipitation in heated linear alkane
3. Blending of polystyrene with other polymers for improved mechanical properties

Results and Discussion

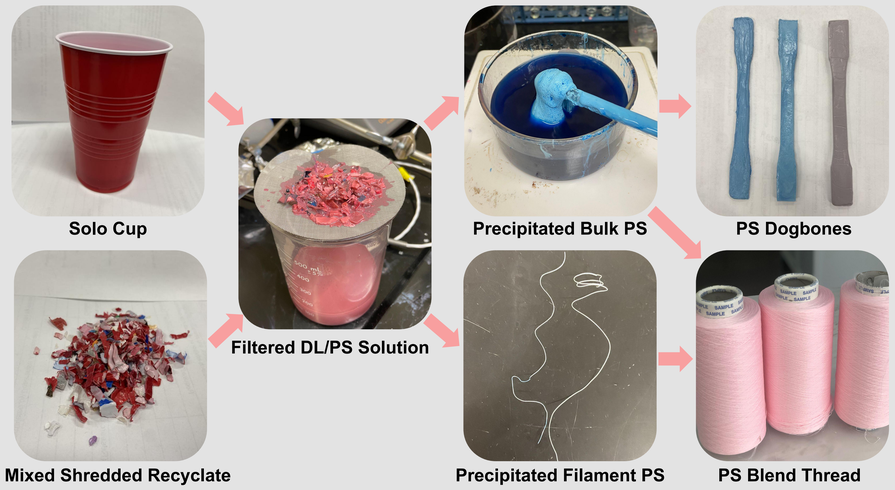
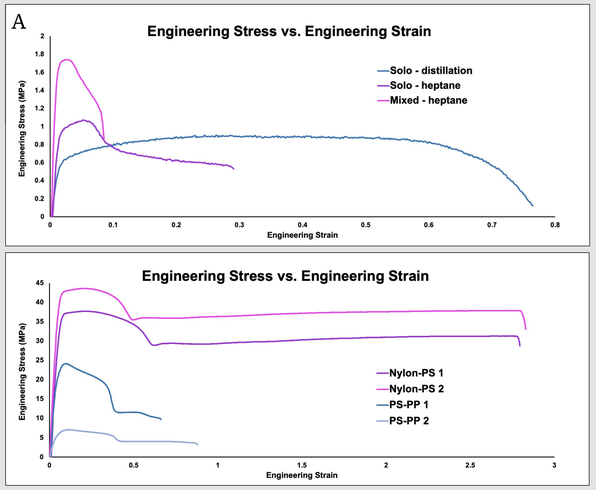


Figure 1. Flowchart of the Research Process



B

Sample	Young's Modulus (GPa)	Tensile Strength (MPa)	Yield Strength (MPa)	Strain at break (mm/mm)
Polystyrene [2]	0.3 - 3.6	5.5 - 60.7	4.22 - 59	.004 - .7
Solo - distillation	0.07	1.1	0.649	0.726
Solo - heptane	0.147	1.9	1.648	0.261
Mixed - heptane	0.303	2.7	2.332	0.048
Polyester [3]	0.1 - 1.6	2.0 - 56.5	3.9 - 72.2	.08 - 9
PP/PS 1	0.852	30.8	18.986	0.621
PP/PS 2	0.823	30.4	15.138	0.829
Nylon/PS 1	0.907	46.3	27.98	2.75
Nylon/PS 2	1.014	45.2	21.578	2.79

Figure 2. (A) Stress strain curve and (B) mechanical properties for virgin and recycled (via distillation and heptane) PS, alongside blends of PS with nylon and polypropylene. Both the blends and the recycled dog bones are within or close to their expected respective literature values (polyester and polystyrene).

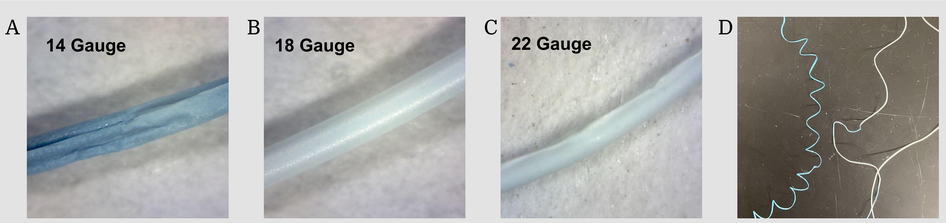


Figure 3. (A, B, C) Filaments extruded from a 20 wt% solution of DL/PS at 0.05 mL/min (optimal parameters for solution concentration and injection speed). The 18 gauge diameter needle produced the smoothest and most uniform filament. (D) Filament color comparison showing a lower dye concentration in the filament that spent longer in heptane bath (right).

Results and Discussion, cont.

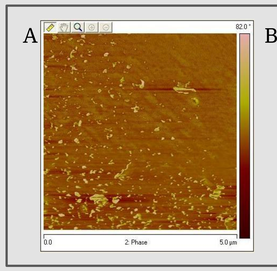


Figure 4. AFM images for polymer blends (A) Nylon/PS 2 and (B) PP/PS 1 show PS domains embedded in a larger Nylon or PP matrix. The shape of the domains suggest that compatibilization of the blends was successful.

Conclusion & Future Work

The separation of PS from contaminates and other polymers is very promising, as it drastically cuts down on the water usage and manual labor required to recycle the PS. Clean PS can then be successfully extracted from solution via pouring or injecting into room temperature heptane. Distillation and heptane precipitation have been used at a commercial scale, although for non-dyed expanded PS, indicating their scalability.[4] Finally, our blends were well compatibilized and resulted in material comparable to polyester.

Future work on this project could entail

- Determination of the ideal weight percent of PS in solution
- Furthering of the wet-spinning process by stretching the generated thread to produce molecular chain alignment
- Vacuum evaporation of the PS/D-L, allowing for lower temperature processing and more ease in D-L removal
- Separation of the Heptane/D-L/Dye Solution, potentially via distillation, in order to reuse the components

Acknowledgements & Citations

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[1] Friedman, Vanessa. "The Biggest Fake News in Fashion." *The New York Times*, 20 Dec 2018, https://www.nytimes.com/2018/12/18/fashion/fashion-second-biggest-polluter-fake-news.html. Accessed 29 April 2021.

[2] "Overview of materials for polystyrene, molded, unreinforced." *MatWeb*, http://www.matweb.com/search/datasheet.aspx?matguid=df6. Accessed 29 April 2021.

[3] "Overview of materials for polyester thermoplastic elastomer." *MatWeb*, http://www.matweb.com/search/DataSheet.aspx?MatGUID=0619837e. Accessed 29 April 2021.

[4] Noguchi, Tsutomu, et al. "A new recycling system for expanded polystyrene using a natural solvent. Part 2. Development of a prototype production system." *Packaging Technology and Science: An International Journal* 11.1 (1998): 19-37.